Enhanced Vapor Recovery Emissions Quantification

November 5, 1998

The vapor recovery system (VRS) at a gasoline dispensing facility (GDF) is subject to many factors which may affect its emissions. The purpose of this appendix is to present the assumptions and calculations regarding quantification of emissions at service stations or GDF which are being used to support the proposed changes to the vapor recovery program. The proposed changes include Onboard Refueling Vapor Recovery Compatibility (ORVRC), In-Station Diagnostics (ISD) and other Program Improvements (PI). All three of these components, constitute the proposed "Enhanced Vapor Recovery" (EVR) program.

Emissions have been estimated for the following cases:

(0)   Baseline; No Onboard Refueling Vapor Recovery (ORVR) Vehicles (1995 Emission Inventory), without ORVRC, ISD, and PI.

(1a)   Year 2007, 50% ORVR Penetration; 17% of stations are equipped with assist systems; without ORVRC, ISD, and PI.

(1b)   Same as 1a; except that 50% of GDF are equipped with assist systems in 2007.

(2a)   Same as 1a; except with ORVRC and without ISD and PI.

(2b)   Same as 1b; except with ORVRC and without ISD and PI.

(3a)   Same as 1a; except that all EVR components, (ORVRC, ISD, and PI) are in operation.

(3b)   Same as 1b; except that all EVR components, (ORVRC, ISD, and PI) are in operation.

Revised Assumptions for Calculating Emissions

This document has updated several assumptions since the July 1998 draft.

(1)   **Percentage of Assist Systems**

Previously, 100% assist systems was used as a worst case estimate. Data collected by the Districts show that 17% of existing systems are assist. The current ratio is assumed constant for this analysis in cases 1a, 2a, and 3a. Some anecdotal information indicates assist systems are gradually replacing balance systems. To account for this, cases 1b, 2b,

and 3b assume 50% in 2007. A straight-line change from 17% to 50 % in 2007 (and beyond) is assumed in the attached calculations. This difference is represented in the third column (constant) and the fifth column (variable) of Table 1. All further references to columns should be understood as relating to values in Table 1.

(2)   **ORVR Vapor Growth Emissions**

Previously, we used 53.84 tons per day statewide as our worst case assumption. This was based on theoretical calculations for increased fugitive emissions due to ORVR fuelings. Now we are using an emission factor for emissions attributable to ORVR obtained from results of 1998 field testing by ARB staff. A worst case value assuming 100 % assist systems and 100% ORVR penetration is calculated as 9.89 tons/day (calculation shown below).

In the ARB field tests, the ORVR simulated fraction was 45%, but for simplicity we will apply these results for 50% ORVR penetration. We will vary the fraction of GDFs that are assist facilities in the scenario calculations. The 0.17 value is based on results from a recent survey of Districts which shows vacuum assist facilities as 17% of all facilities. Thus, the value of 17% was chosen for the constant assist factor. The variable assist factor starts at 0.17 and rises on a straight line to 0.50 at 2007, and beyond.

Both Baseline (existing 1998 vehicle population) and ORVR simulation at 45% ORVR penetration were measured in the ARB tests. Subtracting the baseline emission value from the ORVR simulation value provides an emission factor of 0.5346 #/1000 gal.for excess emissions due to ORVR at 45% penetration. To estimate emissions at other ORVR penetrations, we assumed a linear relationship of the ORVR excess emissions so that for 100% ORVR the emission factor is 1.188 #/1000 gal as shown below:

$$(0.5346 \text{ \#/1000 gallons}) (1 / 45\%) = 1.188 \text{ \#/1000 gal}$$

The total statewide tons/day ORVR emission increase is then calculated as follows:

$$(13.5 \text{ E9 gal/yr}) (1\text{yr}/365 \text{ dy}) (\% \text{ ORVR VMT}) (\% \text{ Assist}) (1.188 \text{ \#/1000 gal}) (1\text{ton}/2000 \text{ \#}) =$$

$$(\% \text{ ORVR VMT})(\% \text{ Assist})(21.98 \text{ tons/day})$$

(3)   Hydrocarbon Concentration Returned to UST by ORVR Fueling

A CARB test on one mechanical seal vehicle indicates that mechanical seals act like conventional fillpipes in that the same hydrocarbon concentration is returned to the underground storage tank as a non-ORVR vehicle. However the penetration of the fleet by vehicles with mechanical seals is estimated by MSCD to consist of 6% of the total ORVR vehicles, consisting in sales by two luxury car makers. For now, we will consider the hydrocarbon concentration returned by mechanical seals to be 0%.

The average ORVR vapor return concentration for non-mechanical seals is 5% hydrocarbon as measured in ARB studies on ORVR prototypes. The vapor growth emissions for ORVR are now based on field test results where ambient air was returned to the underground storage tank while to simulate ORVR fueling.

EXPLANATION OF THE BASELINE CASE

(0)   Baseline, No ORVR Vehicles (1995 Emission Inventory)

In the table below, the controlled values are taken directly from ARB's 1995 Emission Inventory. In this and other tables, the Uncontrolled values are Controlled / (1 - % Control).

BASELINE

Baseline	Controlled (tons/day)	Uncontrolled (tons/day)	% Control Assumed
Working Emissions	13.65	136.50	90%
Spillage Emissions	11.71	11.71	constant @ 0%
Displacement Emissions	19.64	140.29	86%
Breathing Emissions	2.84	20.29	86%
Totals	47.84	308.79	85%

The categories used in CARB's Emission Inventory (EI) and the emissions associated with each category are discussed below. The four categories in the EI which relate to GDF are Working Emissions, Spillage Emissions, Displacement Emissions, and Breathing Emissions. The calculations below are on a statewide basis in tons/day (ROG or TOG).

Working Emissions are caused by bulk fuel deliveries to the GDF. Working emissions are mostly caused by vent emissions due to the rapid loading rates (400 gallons/minute) pushing vapors out

of the underground tank. As such, Working Emissions are not affected by assumptions about % Assist penetration or ORVR performance. CARB's EI Baseline for 1995 assumes 90% control on uncontrolled emissions of 136.50 tons/day to yield 13.65 tons/day.

Spillage Emissions are caused by customers using the nozzles at the GDF. VRS must meet a spillage performance standard of 0.42 #/1000 gallons. CARB's EI Baseline for 1995 assumes no control to yield 11.71 tons/day.

Displacement Emissions occur at the nozzle/fillpipe interface by liquid pushing vapors out of the vehicle tank as it is filled. CARB's EI Baseline for 1995 assumes 86% control on uncontrolled emissions of 140.29 tons per day to yield 19.64 tons/day. The 86% control factor is based on a 90% control efficiency for all Phase 1 & 2 systems (5% defect rate assumed) and 4% of the total dispensers are without Phase 2 controls.

ORVR systems are assumed to achieve 95% control of displacement emissions.

Breathing Emissions are caused by condensation and evaporation and temperature variations in and ingestion of air into the VRS. The EI baseline assumes 86% control on uncontrolled emissions of 20.29 tons/day to yield 2.84 tons/day.

Case 1a

Emissions are found as the sum of displacement emissions, breathing emissions, working emissions and spillage emissions as shown in Table 1a.

Table 1a: Case 1a (w/o ORVRC, ISD, and PI)

w/o ORVRC, ISD, and PI	Controlled (tons/day)	Uncontrolled (tons/day)	% Control Assumed
Working Emissions	13.65	136.50	90%
Spillage Emissions	11.71	11.71	constant @ 0%
Displacement Emissions	9.82 3.51	70.15 70.15	50% @ 86% 50% @ 95%
Breathing Emissions	1.42 3.29	10.15 10.15	50% @ 86% [50% (20.29*0.14 + 0.17*21.98)] = actual value, not % controlled
Totals	43.40	308.81	86%

Displacement emissions are found as the sum of displacement emissions for non-ORVR and ORVR vehicles weighted by the expected fraction of vehicle miles traveled by ORVR vehicles in each year. Displacement emissions from the ORVR vehicles are assumed 95% controlled while displacement emissions from non-ORVR vehicles are assumed 86% controlled. Uncontrolled displacement emissions are taken as 140.29 TPD based on emissions inventory estimates.

Breathing emissions are found as the sum of breathing emissions for non-ORVR and ORVR vehicles (again weighted by the expected fraction of vehicle miles traveled by ORVR vehicles in each year) and an additional ORVR-incompatability emissions component proportional to the fraction of ORVR vehicles and to the percentage of service stations which are assist type. The ORVR-incompatibility component is based on extrapolations of results of tests in El Sobrante and is 21.98 TPD if all vehicles are ORVR and all stations are assist; this is reduced based on the expected fraction of vehicle miles traveled by ORVR vehicles in each year and the assumption that 17% of stations (the estimated current level) are assist type. Breathing emissions from both ORVR and non-ORVR vehicles are assumed 86% controlled. Uncontrolled breathing emissions (not including the ORVR incompatibility emissions component) are taken as 20.29 TPD based on emissions inventory estimates. The ORVR incompatibility emissions component is taken as 0% controlled.

Uncontrolled Phase I working emissions are taken as 136.50 TPD based on emissions inventory estimates. Phase I working emissions are assumed 90% controlled, again following emissions inventory estimates.

Uncontrolled spillage emissions are taken as 11.71 TPD based on emissions inventory estimates and 0% control is assumed.

Projected emissions for case 1a decline as ORVR cars are introduced because the displacement emissions control level is assumed improved from 86% to 95% in ORVR car fueling and the magnitude of this emissions saving is larger than the additional ORVR incompatibility component of emissions attributable to vapor growth provoked by intake of lean, unsaturated air at assist stations.

Case 1b

This case is identical to Case 1a with the sole exception that a straight-line growth in the number of assist-type stations to 50% in 2007 (with similar growth thereafter) is assumed.

Table 1b: Case 1b (w/o ORVRC, ISD, and PI)

w/o ORVRC, ISD, and PI	Controlled (tons/day)	Uncontrolled (tons/day)	% Control Assumed
Working Emissions	13.65	136.50	90%
Spillage Emissions	11.71	11.71	constant @ 0%
Displacement Emissions	9.82 3.51	70.15 70.15	50% @ 86% 50% @ 95%
Breathing Emissions	1.42 6.91	10.15 10.15	50% @ 86% [50% (20.29*0.14 + 0.50*21.98)] = actual value, not % controlled
Totals	47.02	308.81	85%

The assumed increase in assist stations aggravates the ORVR incompatibility emissions component. An initial decline in emissions with introduction of ORVR vehicles is still projected because of the magnitude of the displacement emissions savings when fueling ORVR vehicles. As the projected number of assist stations increases over the years, however, projected emissions flatten and then begin to rise.

Case 2a

This case is identical to case 1a except that 100% control of the ORVR incompatibility emissions component is assumed.

Table 2a: Case 2a (w/ ORVRC, w/o ISD and PI)

w/o ORVRC, ISD, and PI	Controlled (tons/day)	Uncontrolled (tons/day)	% Control Assumed
Working Emissions	13.65	136.50	90%
Spillage Emissions	11.71	11.71	constant @ 0%
Displacement Emissions	9.82 3.51	70.15 70.15	50% @ 86% 50% @ 95%
Breathing Emissions	1.42 1.42	10.15 10.15	50% @ 86% 50% @ 86%
Totals	41.53	308.81	87%

The emissions projected under case 2a decline more steeply than case 1a as ORVR vehicles are introduced, because the emissions from ORVR incompatibility no longer offset any portion of the displacement emissions savings assumed when fueling ORVR vehicles.

Case 2b

This case is identical to case 2a except that an increase in the number of assist stations to 50% in 2007 is assumed as in case 1b. This assumption, and the assumption that ORVR incompatibility emissions are 100% controlled distinguish case 2b from case 1a.

Table 2b: Case 2b (w/ ORVRC, w/o ISD and PI)

w/o ORVRC, ISD, and PI	Controlled (tons/day)	Uncontrolled (tons/day)	% Control Assumed
Working Emissions	13.65	136.50	90%
Spillage Emissions	11.71	11.71	constant @ 0%
Displacement Emissions	9.82 3.51	70.15 70.15	50% @ 86% 50% @ 95%
Breathing Emissions	1.42 1.42	10.15 10.15	50% @ 86% 50% @ 86%
Totals	41.53	308.81	87%

Emissions projected under case 2b are identical to those projected under case 2a because the increase in assist stations has no effect due to the assumed 100% control of ORVR incompatibility emissions.

Case 3a

This case is identical to case 2a (ORVR incompatibility emissions assumed 100% controlled) except that the level of control of displacement emissions, breathing emissions and working emissions is assumed to be 95% for ORVR and non-ORVR vehicles alike due to in station diagnostics and program improvements which keep vapor recovery systems operating at their design efficiency.

Table 3a: Case 3a (w/ ORVRC, ISD, and PI)

w/o ORVRC, ISD, and PI	Controlled (tons/day)	Uncontrolled (tons/day)	% Control Assumed
Working Emissions	6.83	136.50	95%
Spillage Emissions	11.71	11.71	constant @ 0%
Displacement Emissions	3.51 3.51	70.15 70.15	50% @ 95% 50% @ 95%
Breathing Emissions	0.51 0.51	10.15 10.15	50% @ 95% 50% @ 95%
Totals	26.57	308.81	91%

Emissions projected under this scenario are reduced as soon as the proposed improvements are in place and remain constant thereafter. Because immediate compliance is unrealistic, the results of compliance will follow an "S" shaped curve for the first four years. The amount of emissions reduction is larger than in case 2a because, in addition to control of ORVR incompatibility emissions assumed in case 2a, improved 95% control of non-ORVR displacement emissions (previously assumed 86% controlled), ORVR and non-ORVR breathing emissions not due to ORVR incompatibility (previously assumed 86% controlled) and working emissions (previously assumed 90% controlled). The emissions saved by these assumed improvements in control levels are substantial. There is no variation of projected emissions over time as ORVR vehicles become more common because the 95% control level assumed applies to ORVR and non-ORVR vehicles equally (making ORVR fraction irrelevant) and 100% control of ORVR incompatibility emissions is assumed (again making ORVR fraction irrelevant).

Case 3b

This case is identical to case 3a except that the number of assist stations is assumed to increase, reaching 50% by 2007.

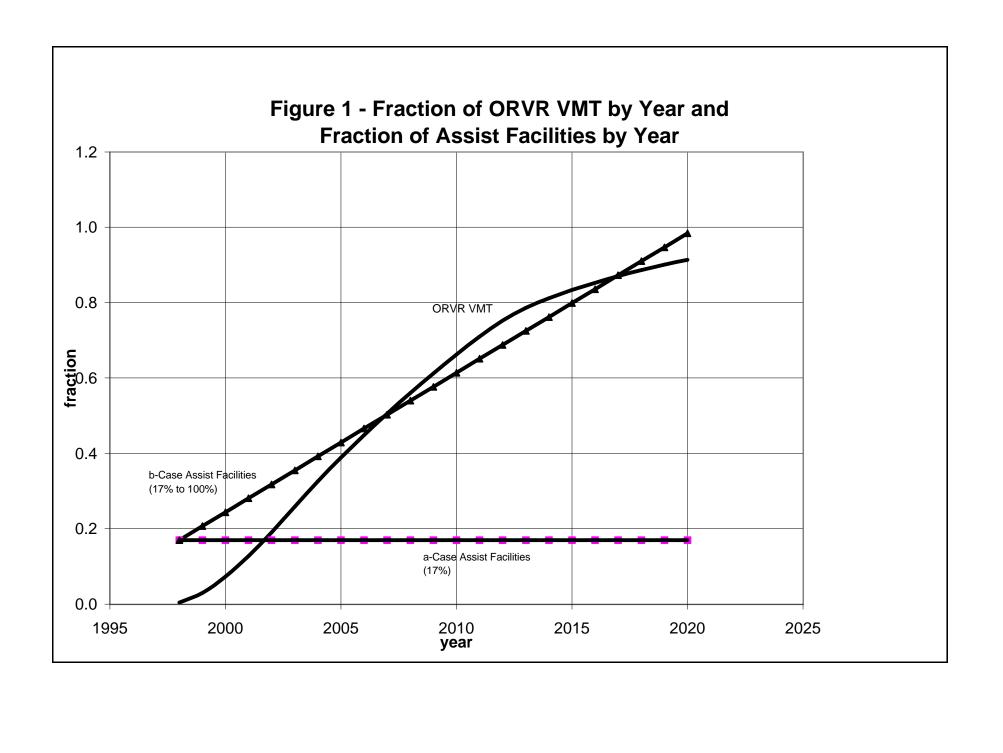**Table 3b: Case 3b (w/ ORVRC, ISD, and PI)**

w/o ORVRC, ISD, and PI	Controlled (tons/day)	Uncontrolled (tons/day)	% Control Assumed
Working Emissions	6.83	136.50	95%
Spillage Emissions	11.71	11.71	constant @ 0%
Displacement Emissions	3.51 3.51	70.15 70.15	50% @ 95% 50% @ 95%
Breathing Emissions	0.51 0.51	10.15 10.15	50% @ 95% 50% @ 95%
Totals	26.57	308.81	91%

Because ORVR incompatibility associated with assist stations is assumed to be 100% controlled, the increase in assist stations has no affect and projected emissions, under case 3b, are identical to those projected under case 3a.

EXPLANATION OF ATTACHED TABLES AND FIGURES

Table 1 has all of the values from which Figures 1 & 2 are plotted. Table 2 has the equations which are used to plot Figures 1 & 2. Figure 1 shows the fraction of ORVR VMT and fraction of Assist facilities by year. Figure 2 shows the cases plotted on one figure from 1998 to 2010.

Table 1: Values for Each Case

Model Year	Model Year (Fraction ORVR VMT)	Assist Facilities (Fraction)	Baseline	Assist Facilities (Fraction)		w/o ORVRC, ISD, & PI*		w/ ORVRC, w/o ISD, & PI*		w/ ORVRC, ISD, & PI*	
			Baseline			Case 1b		Case 2b		Case 3b	
1998	0.0043	0.17	47.84	0.17		47.80		47.79		47.79	
1999	0.0300	0.17	47.84	0.21		47.60		47.46		44.51	
2000	0.0732	0.17	47.84	0.24		47.31		46.92		37.17	
2001	0.1270	0.17	47.84	0.28		47.02		46.24		31.50	
2002	0.1900	0.17	47.84	0.32		46.77		45.44		27.57	
2003	0.2591	0.17	47.84	0.36		46.59		44.57		26.57	
2004	0.3261	0.17	47.84	0.39		46.53		43.72		26.57	
2005	0.3890	0.17	47.84	0.43		46.60		42.93		26.57	
2006	0.4486	0.17	47.84	0.47		46.77		42.18		26.57	
2007	0.5054	0.17	47.84	0.50		47.05		41.46		26.57	
2008	0.5603	0.17	47.84	0.54		47.42		40.77		26.57	
2009	0.6126	0.17	47.84	0.58		47.88		40.11		26.57	
2010	0.6628	0.17	47.84	0.61		48.42		39.47		26.57	
2011	0.7104	0.17	47.84	0.65		49.04		38.87		26.57	
2012	0.7528	0.17	47.84	0.69		49.72		38.34		26.57	
2013	0.7863	0.17	47.84	0.73		50.44		37.91		26.57	
2014	0.8123	0.17	47.84	0.76		51.19		37.59		26.57	
2015	0.8340	0.17	47.84	0.80		51.96		37.31		26.57	
2016	0.8530	0.17	47.84	0.84		52.75		37.07		26.57	
2017	0.8705	0.17	47.84	0.87		53.55		36.85		26.57	
2018	0.8867	0.17	47.84	0.91		54.38		36.65		26.57	
2019	0.9012	0.17	47.84	0.95		55.22		36.46		26.57	
2020	0.9134	0.17	47.84	0.98		56.06		36.31		26.57	
* in units of tons/day, statewide											

Figure 1 - Fraction of ORVR VMT by Year and Fraction of Assist Facilities by Year

Table 2: Equations for Each Case

1b	=(1-B4)*140.29*0.14+(B4)*140.29*0.05+(1-B4)*20.29*0.14+(B4)*(20.29*0.14+E4*21.98*1)+13.65+11.71
2b	=(1-B4)*140.29*0.14+(B4)*140.29*0.05+(1-B4)*20.29*0.14+(B4)*(20.29*0.14+E4*21.98*0)+13.65+11.71
3b	=(1-$B4)*140.29*0.05+($B4)*140.29*0.05+(1-$B4)*20.29*0.05+(B4)*(20.29*0.05+E4*21.98*0)+6.83+11.71

Variables: B = Fraction ORVR VMT; (1-B) = (Fraction Non-ORVR VMT); C = Assist Systems Constant at 17%;
Assist Systems Varying from 17% in 1998 in a Straight Line through 50% in 2007.

Constants: 140.29 = Uncontrolled (Unc) Displacement Emissions; 20.29 = Unc Breathing Emissions;
21.98 = Breathing Emissions from Unc ORVR Incompatibility; 13.65 = 90% Controlled Working Emissions;
6.83 = 95% Controlled Working Emissions; 11.71 = Unc Spillage Emissions.

Figure 2 - Emissions by Year

Baseline = Case 0

w/o ORVRC, ISD, & PI = Case 1

w/ ORVRC, w/o ISD & PI = Case 2

w/ ORVRC, ISD, & PI = Case 3

Cases 1b - 3b have the Assist fraction vary on a line from 17% straight through 50% at 2007, and are plotted with diamonds.

Baseline

case 1b

cases 2a & 2b

cases 3a & 3b

estimated tons/day

year